

9th Conference of the International Sports Engineering Association (ISEA)

Preliminary study of Accuracy and reliability of high-speed human-motion tracking using miniature inertial sensors

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Accepted 02 March 2012

Abstract

The purpose of this study was to validate a new motion analysis system which uses the technology of inertial sensors (Moven system). This innovative system is composed of 17 miniature inertial sensors attached to the body. The validation procedure consisted in comparing the data of the right hand trajectory collected by the Moven system with those given by an optoelectronic system (Vicon) composed of 6 infrared camcorders. The comparison of kinematic data was performed during a shot put training session in three high level athletes. The results of this preliminary study only concern the velocity module of the hand (on the middle of the second metacarpal) during the shot put. Paired t-test, r correlation coefficient and Bland & Altman test were used to compare the validity and the limit of agreement between the two tools. The results showed no difference between the measurements ($p = 0.066$). The correlation between the tools' measurements is $r > 0.46$. Bland & Altman test showed low reliability (bias $< 0.15 \text{ m}\cdot\text{s}^{-1}$) and accuracy (mean error = $0.63 \text{ m}\cdot\text{s}^{-1}$) between tools. Similar patterns of the right hand velocity curves during the shot put were obtained with both devices. However, there were differences in velocity intensity for some phases of the throw. The differences in sampling frequency and computational algorithms employed by the Moven and Vicon systems could partly explain these differences in shot-put velocity.

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Keywords: Inertial navigation system; shot put; 3D kinematic studies

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1. Introduction

The evaluation of athlete's performance is one of the main issues in coaching, as well as in sports biomechanical analysis. In this aim, the analysis of the complex motions like shot put, without influencing or constraining athletes' activity and with a quick feedback is now becoming mandatory [1]. Shot put is a complex movement that associates translation and rotation [2, 3, 4, 5, 6]. The goal is to release the shot with maximum forward velocity at an angle of approximately forty degrees [2-5, 7, 8, 9, 10, 11]. Nowadays, most of the high level competitors use the spin style whose main purposes are to reach a high rotational speed of the body and to transfer the energy into the shot put [9].

Among the new wearable and lightweight technologies allowing for such assessment, miniature inertial centrals appear to be a good compromise between accuracy and using easily. The Moven system includes this original technology. The Moven system is composed of 17 miniature inertial centrals attached to the body. These sensors combine three-axial accelerometers, gyroscopes, and, magnetometer used for the measurement of a global reference frame. They allow data collection during unconstrained continuous movement over prolonged periods of time, potentially even during training and competition. The advantage of this kind of system seems to be fast reconstruction of the motion patterns and feedback.

Nevertheless, the extraction of the movement related to information from the signal derived from inertial technologies can be exposed to the offset errors and the drifts accumulated over time [16, 17]. It can also be exposed to sensors oscillations caused by the inertia of soft tissues [1, 16]. The purpose of this study was to compare a new motion analysis system that used the technology of inertial sensors with the kinematic data given by an optoelectronic system in sport training conditions. The results of this preliminary study only concern the velocity norm of the right hand during the shot put.

2. Methods

The experiment took place in an indoor hall at the National Institute for Sport, Expertise and Performance. Three male subjects voluntarily participated to this study. All subjects were high level shot putters of the French national team. All subjects were asked to perform three shot puts with standard (7.2 kg) shots. For each subject, only the best shot put (longest distance) was studied. Kinematic data were collected simultaneously with a Moven (Xsens Technologies BV, Enschede, Holland) and Vicon (Vicon Motion systems, Oxford, UK) systems. The Moven system is composed of 16 miniature inertial centrals (nanotechnology inertial motion units, nIMU) attached to the body by straps. Each nIMU contains three gyroscopes, three accelerometers, three magnetometers in a 35-g box about the size of a match box. Each nIMU captures in real time the full 6 degrees of freedom of the body where it is fixed. The subjects wore the Moven capture suit which also included a wireless data link. The sampling frequency was equal to 60 Hz. Kinematic analysis was performed with a modified version of the software provided by Moven. In order to determine the velocity motion, numerical integration of the kinetic data was performed using trapezoid rule. The optoelectronic system (Vicon) consisted of 6 infrared Vicon 612 camcorders. A static calibration around the throwing area was done. A dynamic calibration was performed using a 390 mm stick with two markers moving in the throwing area. The sampling frequency of the Vicon system was 200 Hz. For this experiment, reflective markers were attached on the nIMU sensors of the Moven System. 3D Kinematic data were computed with the software provided with the optoelectronic Vicon system. In order to determine velocity of the reflective markers, numerical derivation of the kinematics data was performed using moving average rule. In the aim to compare velocity data of both systems (Moven versus Vicon), the kinetic data of the Vicon system have been re-sampled at 60 Hz. Data of both systems were synchronised when the shot left the athlete's hand. The validation procedure consisted in comparing the velocity patterns of the middle of the second metacarpal on the right hand computed by the Moven system

with those given by an optoelectronic system (Vicon) composed of 6 infrared camcorders. Paired t-test was used to compare the significant difference between the velocities' data measured with the systems (Vicon, Moven). Correlation coefficient (r) was used to estimate the relation between the velocities' data measured with both systems. A Bland and Altman test [15] was used to define the accuracy and reliability between the kinematic variables of both devices. The results of this preliminary study only concern the velocity module of shot put.

3. Results

The statistical results showed that velocity data computed with both systems were not agreed sufficiently well to be used interchangeably. However the results showed that the velocity data of the two systems presented similar patterns during the whole movement. Results showed no significant difference on velocity data between both system ($p = 0.066$). Correlations between the systems for velocity data was $r > 0.46$ ($p = 6 \times 10^{-6}$). Bland & Altman test showed a very low under estimation (mean bias $< 0.5 \text{ m.s}^{-1}$) of the velocity data using the Moven system and a high reliability (mean reliability $< 0.92 \text{ m.s}^{-1}$) compared with the Vicon system (figure 1). Similar same pattern of shot put velocity curve during the whole movement were obtained with both systems (figure 2).

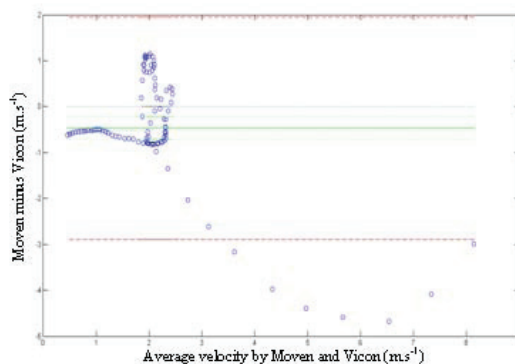


Fig. 1. Bland and Altman plot depicting the limits of bias (green) between the Moven and Vicon systems and the 95% limits of agreement (red) for velocity data. The differences between the Moven and Vicon systems are plotted against each individual's mean for the two systems (blue)

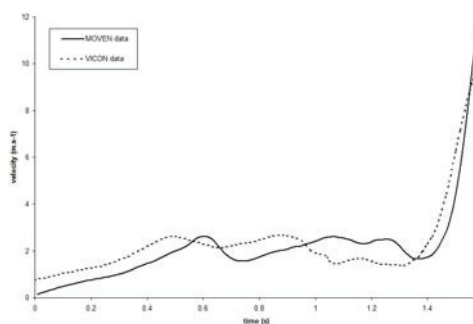


Fig. 2. Example of velocity norm of the right hand during the shot put with a 7.2 kilogram shot for one subject. The curves were computed from the data collected with the Vicon system (continuous lined) and the Moven system (dashed line)

4. Discussion and conclusion

This study has compared velocity data computed with Moven and Vicon systems and has shown that data presented similar patterns and kinematics relations but can not be used interchangeably. The main limit of this study is the difference of computational algorithms employed by the Moven and Vicon systems.

In our study, the result of the paired t-test showed that both systems could be used to estimate velocity data with no significant difference. But the correlation result and the Bland & Altman test showed that some precautions should be taken into account before interchanging both systems. First, correlation between both systems stays very low during the full movement. Second, the Bland & Altman test have showed that i) the Moven system tended to underestimate velocities lower than 2 m.s^{-1} during the first phase of the shot put; ii) velocity computed with both systems seemed similar with decreasing reliability, when it ranked between 2 to 3 m.s^{-1} ; iii) the Moven system tended to underestimate velocities upper than 3 m.s^{-1} during the last phases of the shot put. Different assumptions could explain these results. The low sampling frequency used in the Moven system and the numerical integration used to compute the velocity data may influence the results and improve the drift [13, 16, 18]. The integration process used to compute the velocity data with the Moven system could be sensitive to sensor drifts [18]. In the case of the Vicon system, errors in the velocity data depend of the accuracy positioning of the marker during the recording process. The derivation computing process improved the noise added to the kinematics data and could have influenced the velocity [16]. In our study, the differences in velocity curves obtained with both systems could be explained by the magnetic field sensors that have been altered by the metallic put. The proximity of a metallic mass added by the shot put could disturb the Moven data acquisition process. Indeed, the magnetic field sensors, which contribute to the process of orientation estimation, are sensitive to alteration of the earth magnetic field. In recent studies using inertial sensor system in skiing and sprint running, the inaccuracy of the motion capture system was assumed to be mostly due to geomagnetic variations [14, 1].

However, velocity data computed by both systems presents similar velocity patterns. It can be assumed that the Moven system could be also used even during training without laboratory constraint. The asset of the Moven system is that it could be used to evaluate sport motion in outside sports without restriction of area recording, light conditions, tracking and markers recognition.

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